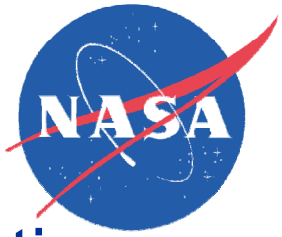
Detecting Thermal Barrier Coating Delamination Using Visible and Near-Infrared Luminescence from Erbium-Doped Sublayers,

J.I. Eldridge* and T.J. Bencic, NASA Glenn Research Center, Cleveland, OH; R.E. Martin, Cleveland State University, Cleveland, OH; J. Singh and D.E. Wolfe, Penn State University, University Park, PA

Nondestructive diagnostic tools are needed to monitor early stages of delamination progression in thermal barrier coatings (TBCs) because the risk of delamination-induced coating failure will compromise engine performance and safety. Previous work has demonstrated that for TBCs composed of yttria-stabilized zirconia (YSZ), luminescence from a buried europium-doped sublayer can be utilized to identify the location of TBC delamination from the substantially higher luminescence intensity observed from the delaminated regions of the TBC. Luminescence measurements from buried europium-doped layers depend on sufficient transmittance of the 532 nm excitation and 606 nm emission wavelengths through the attenuating undoped YSZ overlayer to produce easily detected luminescence. In the present work, improved delamination indication is demonstrated using erbium-doped YSZ sublayers. For visible-wavelength luminescence, the erbium-doped sublayer offers the advantage of a very strong excitation peak at 517 nm that can be conveniently excited a 514 nm Ar ion laser. More importantly, the erbium-doped sublayer also produces near-infrared luminescence at 1550 nm that is effectively excited by a 980 nm laser diode. Both the 980 nm excitation and the 1550 nm emission are transmitted through the TBC with much less attenuation than visible wavelengths and therefore show great promise for delamination monitoring through thicker or more highly scattering TBCs. The application of this approach for both electron-beam physical vapor deposited (EB-PVD) and plasma-sprayed TBCs is discussed.

National Aeronautics and Space Administration



Detecting Thermal Barrier Coating Delamination Using Visible and Near-Infrared Luminescence from Er-Doped Sublayers

J.I. Eldridge and T.J. Bencic
NASA Glenn Research Center

R.E. Martin
Cleveland State University

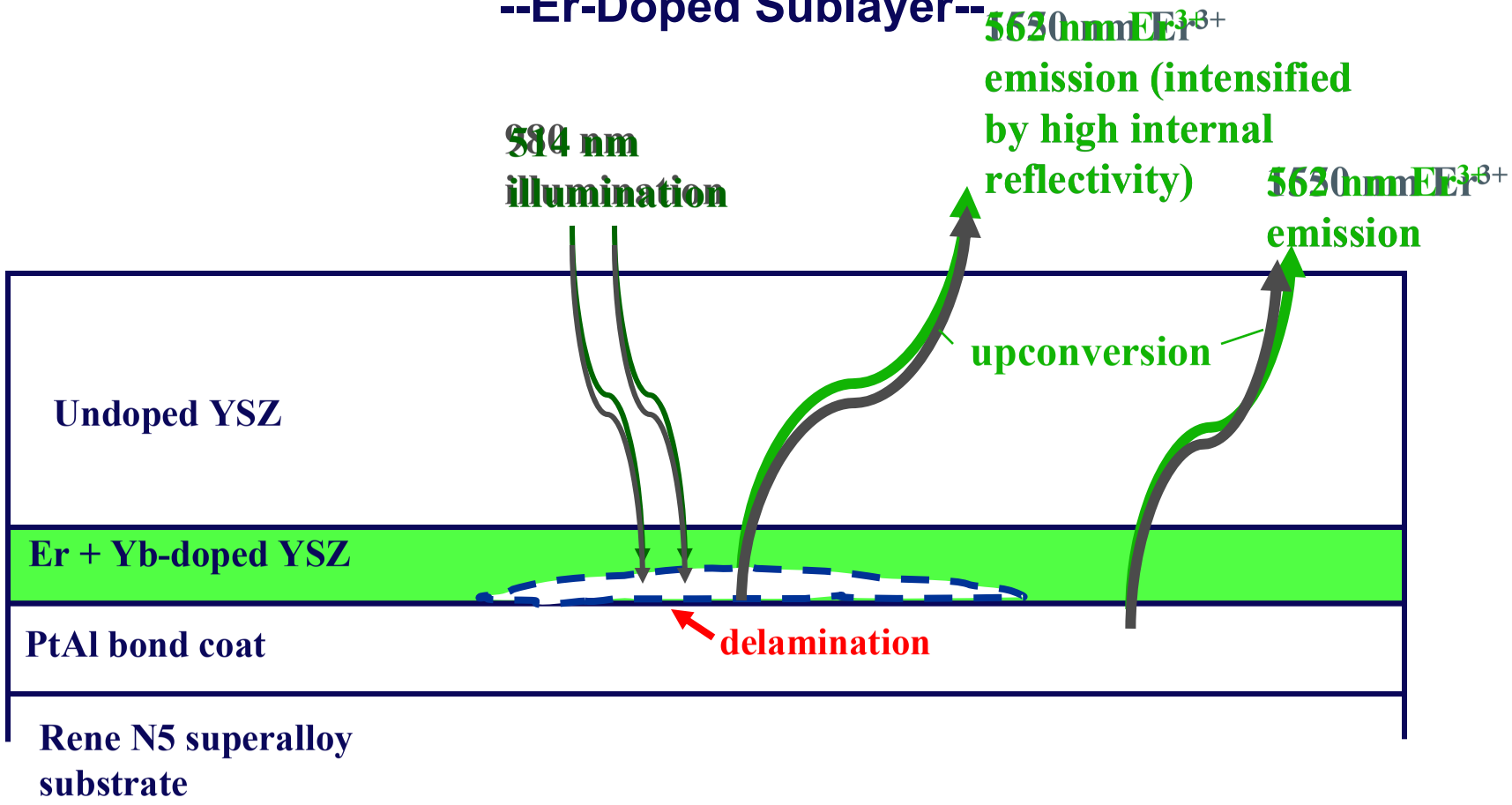
J. Singh and D.E. Wolfe
Penn State University

31st International Cocoa Beach Conference on Advanced Ceramics and Composites
Daytona Beach, FL
January 25, 2007

Background

- Practical & reliable nondestructive diagnostic tools needed for informed assessment of TBC delamination progression & remaining life.
- Two recent approaches have shown promise for monitoring TBC delamination progression:
  - Mid-infrared (MIR) reflectance imaging
  - Luminescence from Eu-doped sublayer.
- Thicker plasma-sprayed TBCs remain difficult.

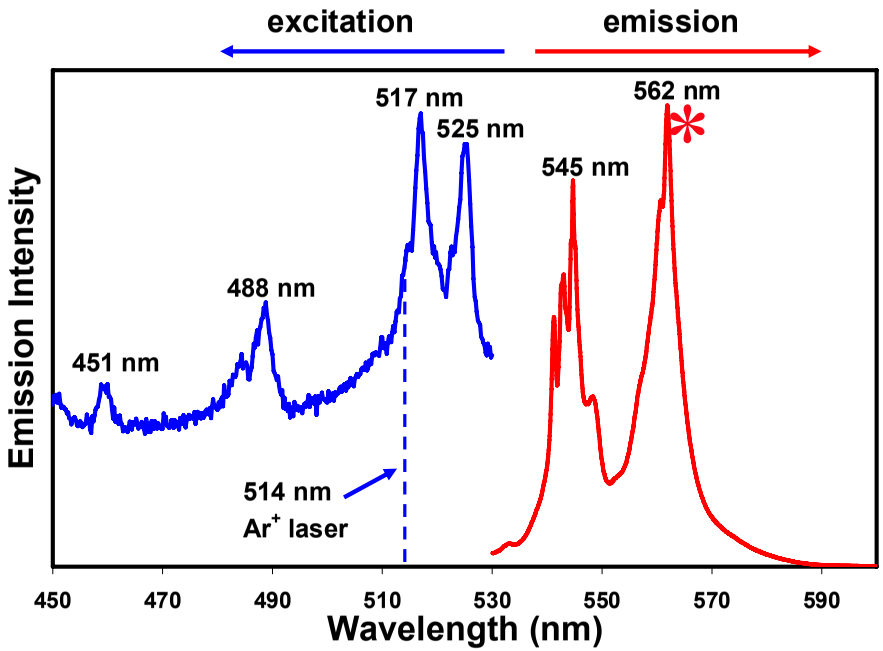
Detecting TBC Delamination by Reflectance-Enhanced Luminescence
--Er-Doped Sublayer--

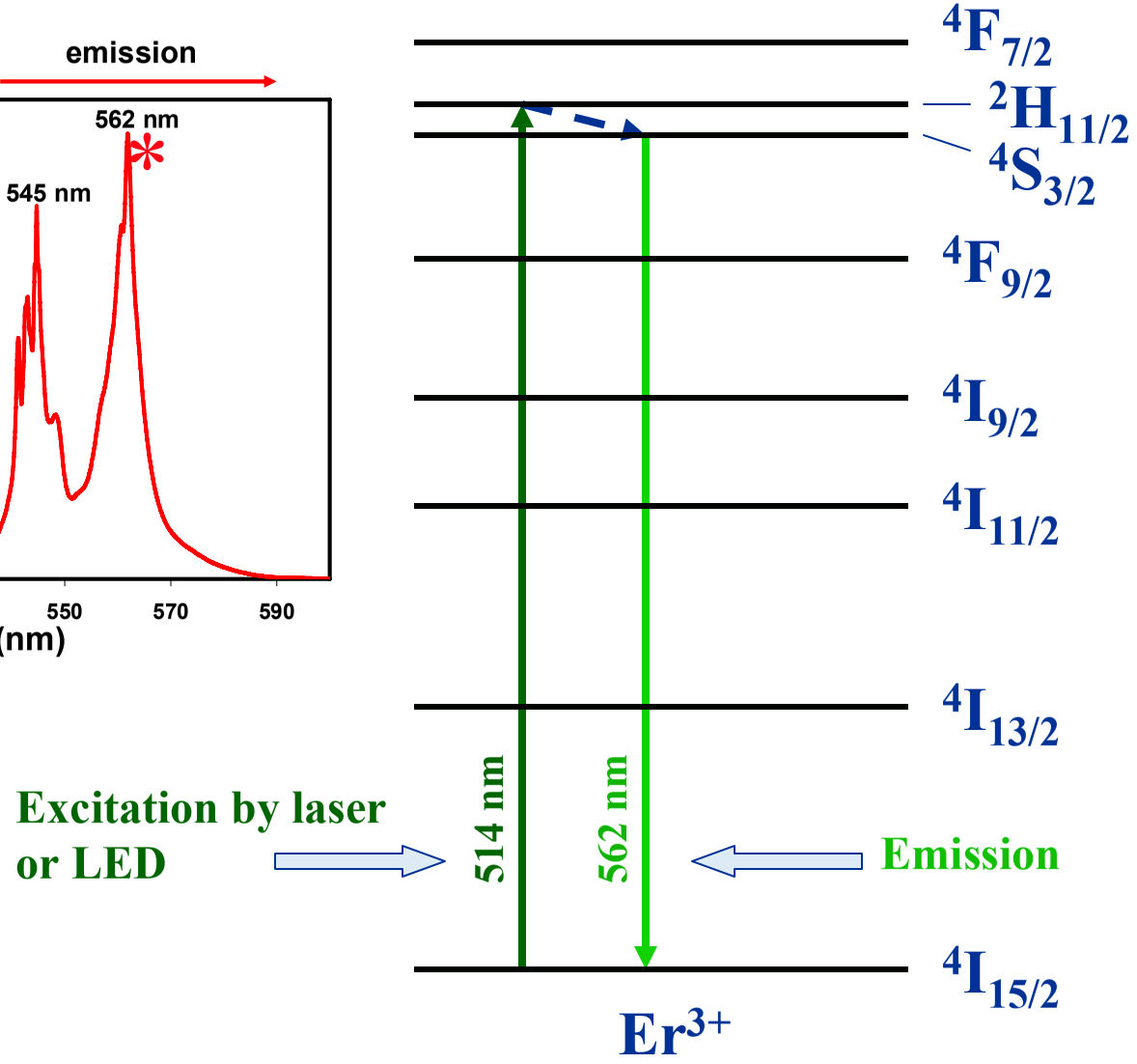


Motivation for erbium doping

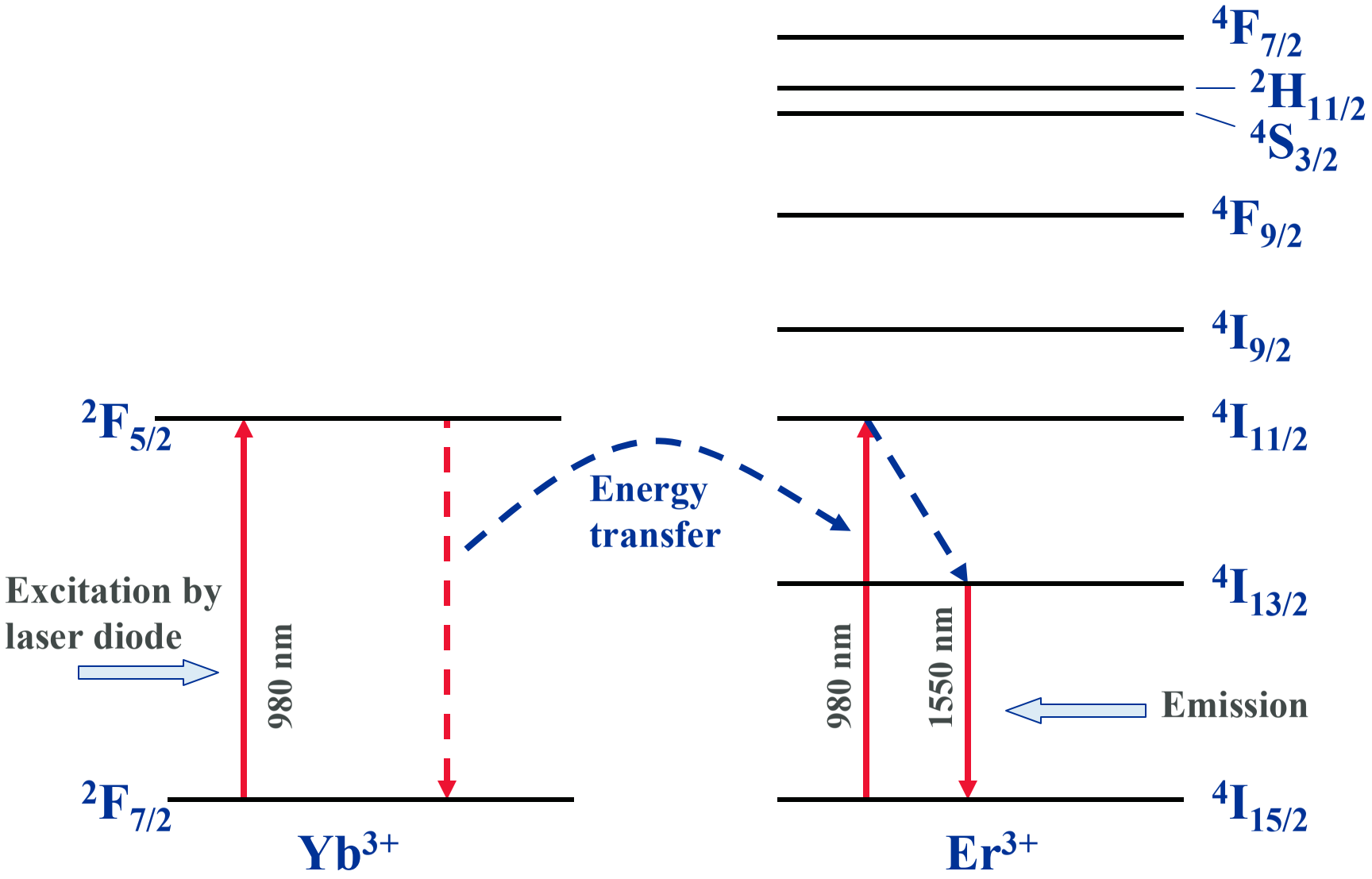
- Produces strong NIR luminescence at wavelength where TBC is much more transparent.
- Produces strong upconversion luminescence with near-zero background.

Er^{3+} Energy Level Diagram
Visible Luminescence

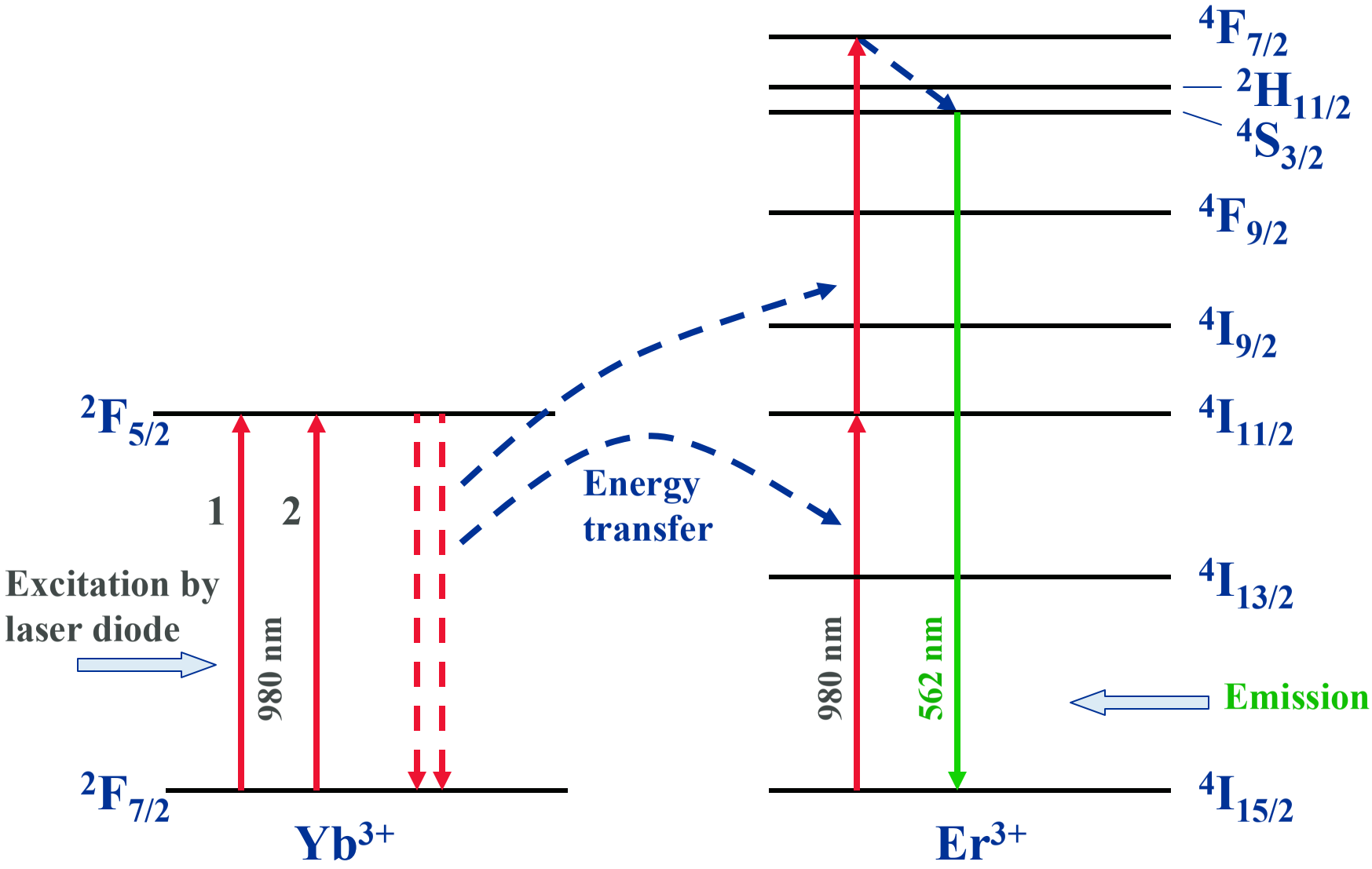




Er^{3+} Energy Level Diagram
NIR Luminescence

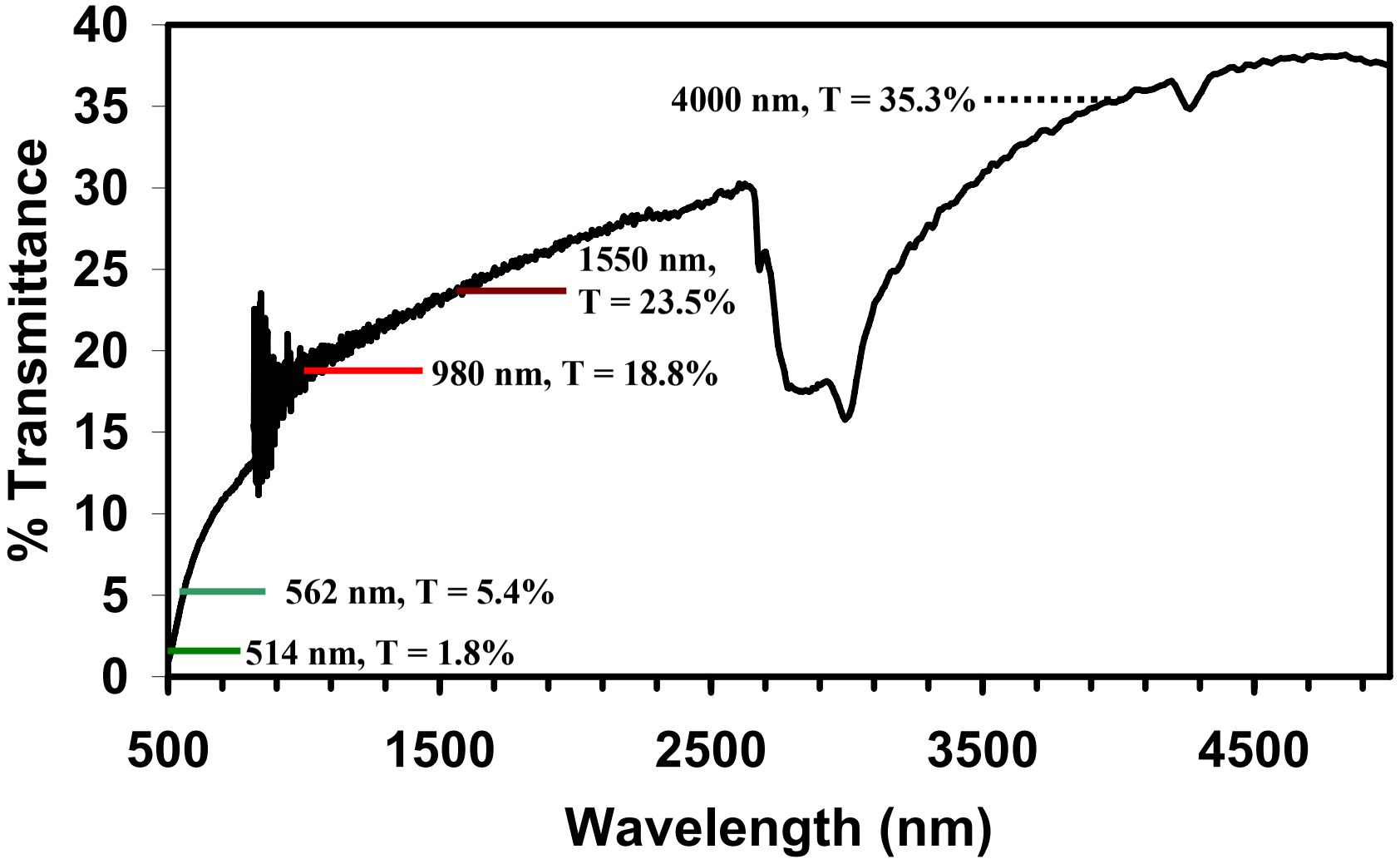


Er^{3+} Energy Level Diagram
Upconversion Luminescence

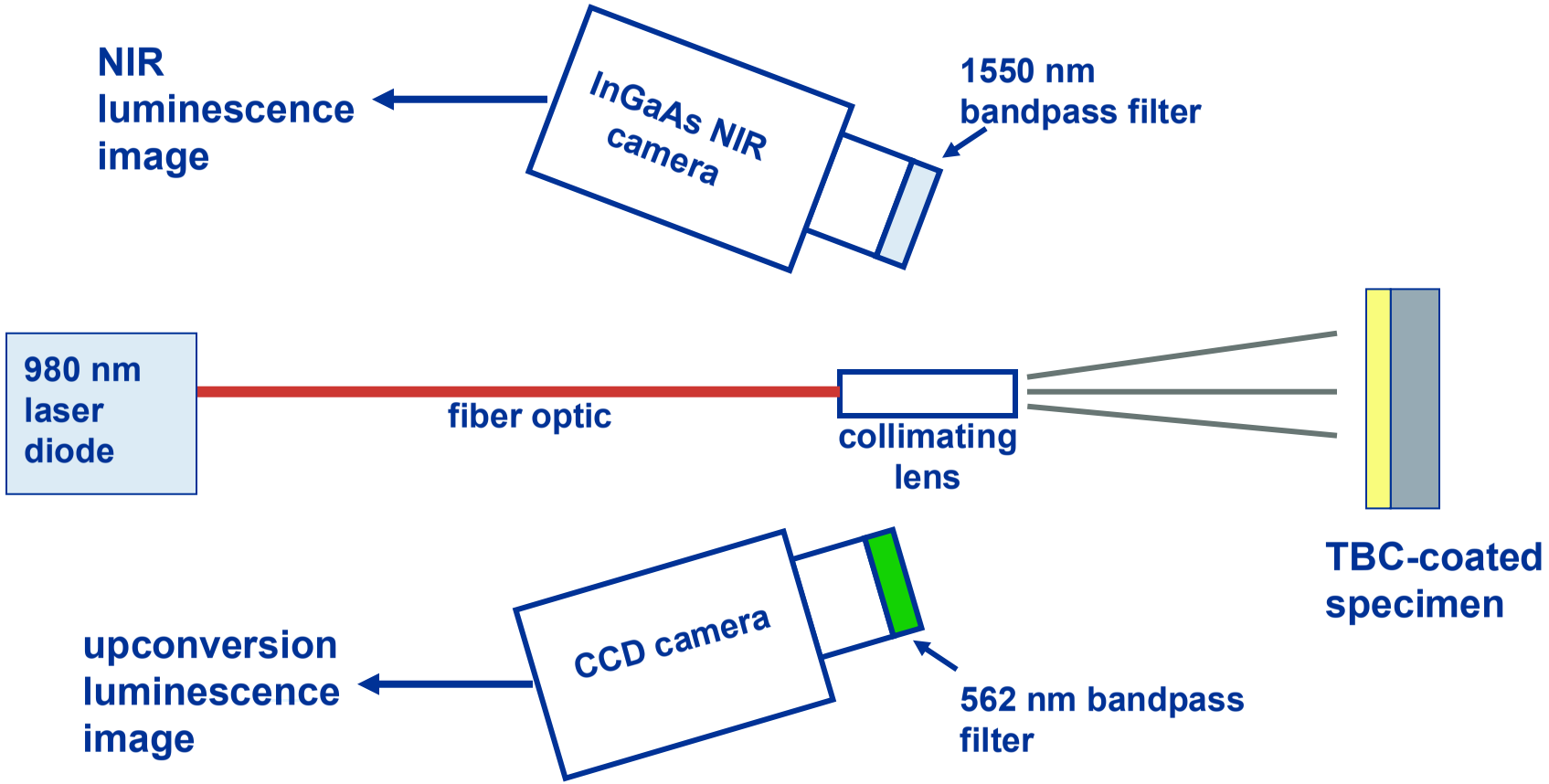


Effect of Wavelength on Luminescence Attenuation

172 μm plasma-sprayed TBC



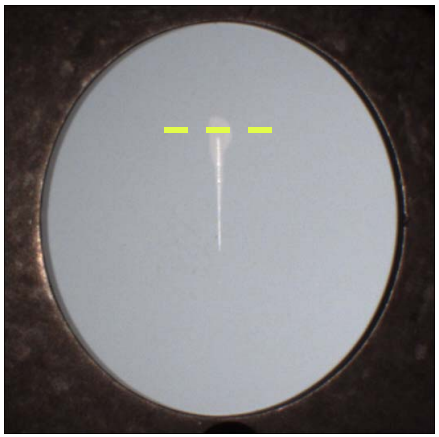
NIR and Upconversion Luminescence Imaging

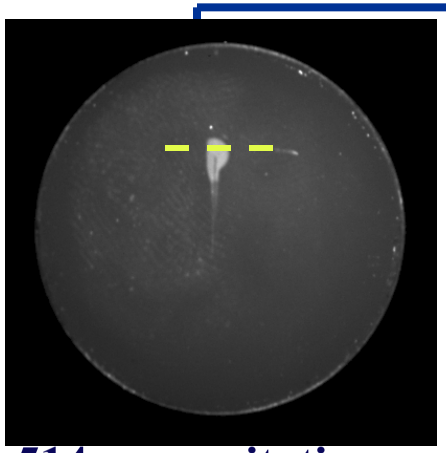


Er^{3+} Luminescence Imaging of Scratch-Induced Delamination for EB-PVD TBC with YSZ:Er(1%),Yb(3%) Base Layer

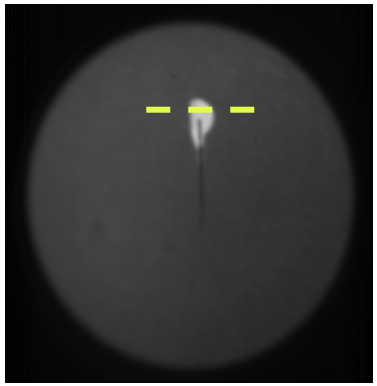
White light image

Luminescence images

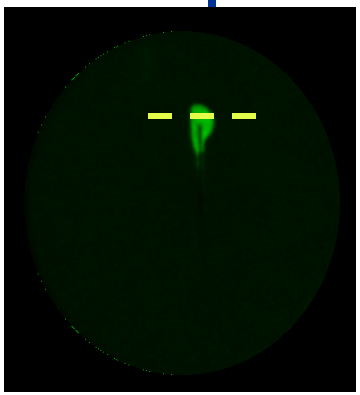




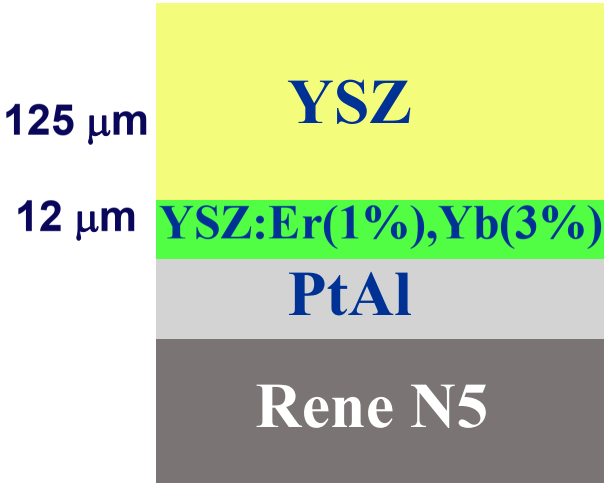
514 nm excitation
563 nm emission
1 sec

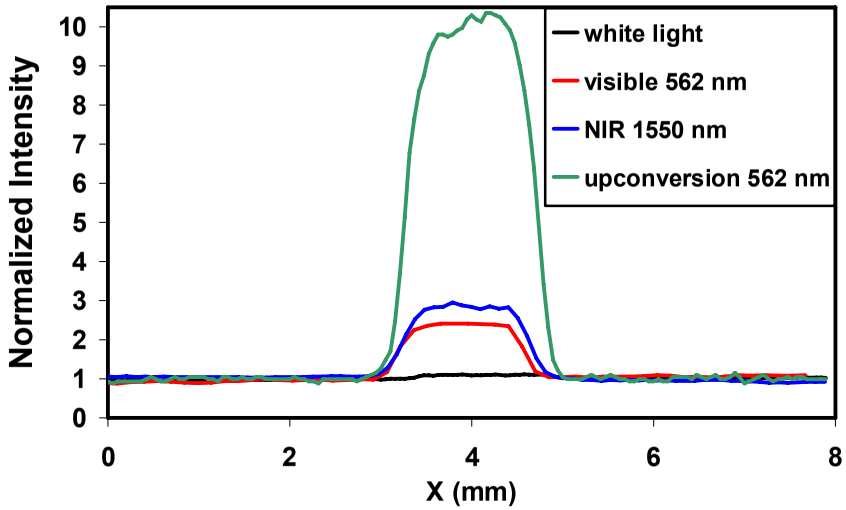


980 nm excitation
1550 nm emission
16 msec



980 nm excitation
560 nm emission
6 sec

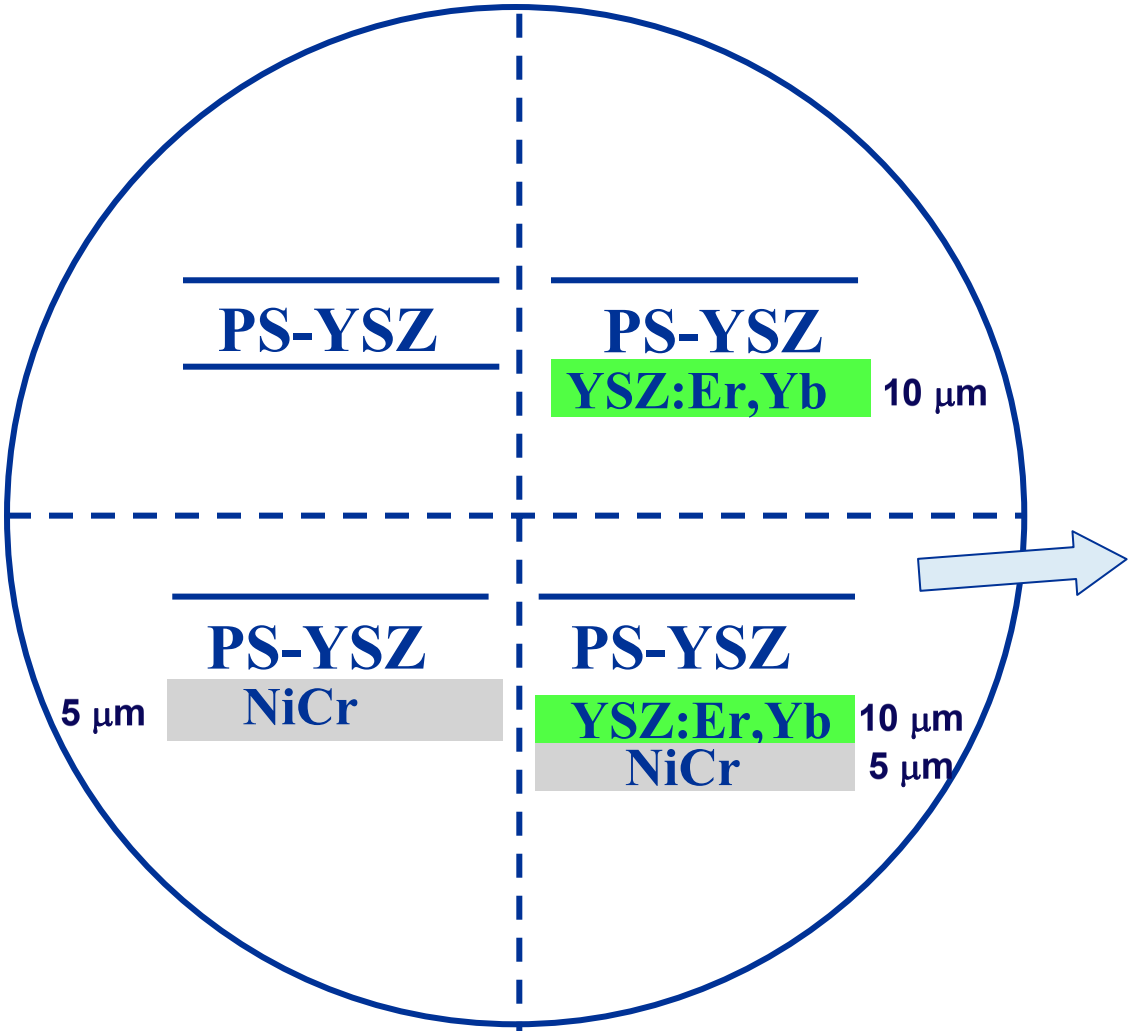




Line Scans across Delaminated EB-PVD TBC Region

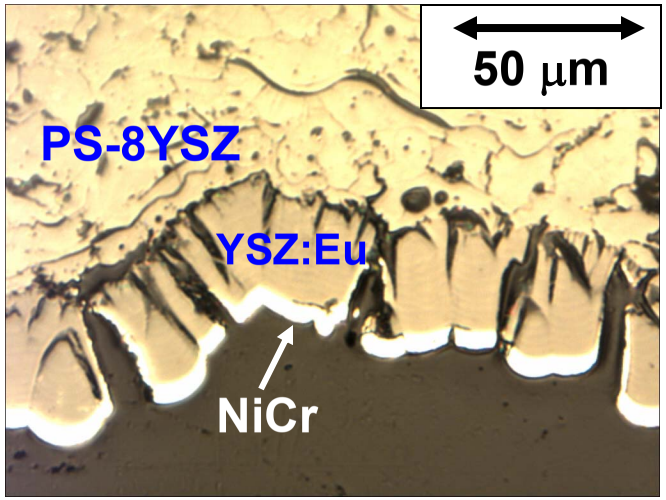
Plasma-Sprayed TBCs

Partitioned Multilayer Coating Design

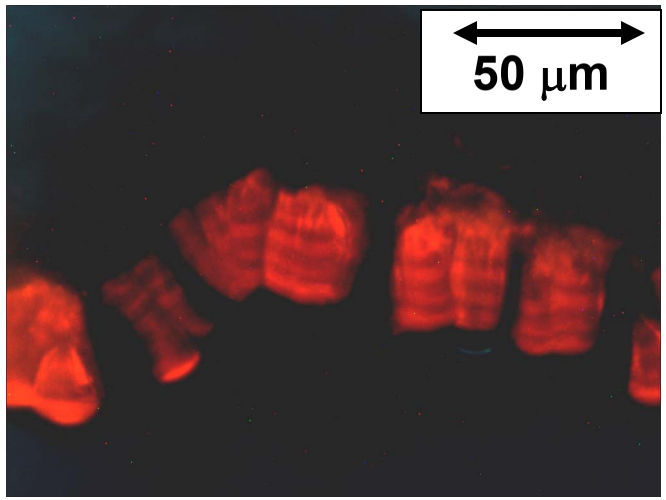


Top View

White light image



UV illumination



Er^{3+} Luminescence Image of Freestanding Plasma-Sprayed YSZ Coating with Partitioned Backside YSZ:Er,Yb & NiCr Coatings

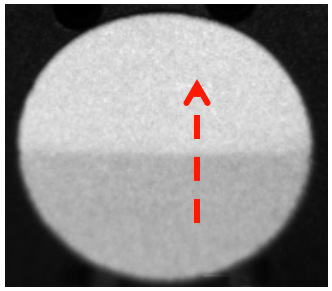
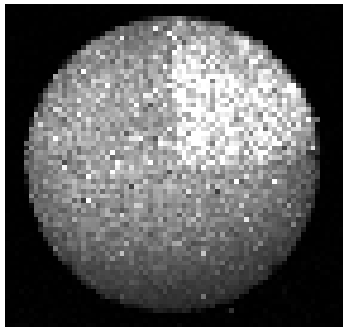
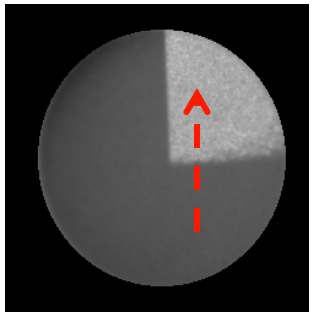
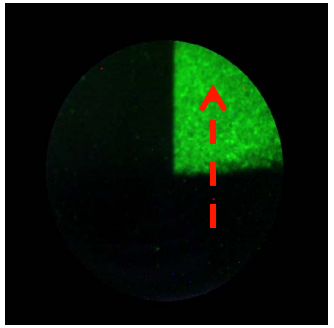
White light

MIR Reflectance
4.0 μm incident
4.0 μm reflected

Visible
514 nm excitation
562 nm emission

NIR
980 nm excitation
1550 nm emission

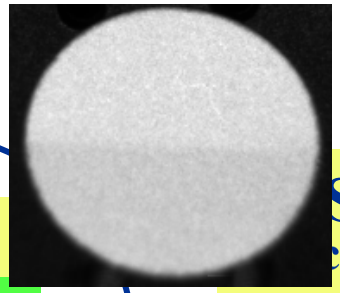
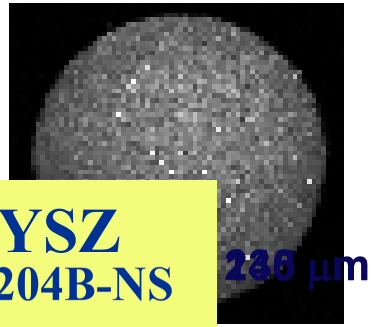
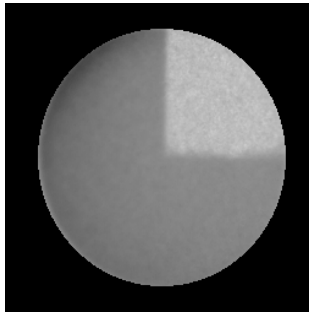
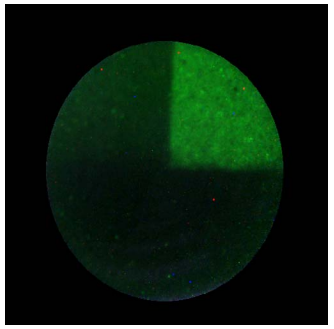
Upconversion
980 nm excitation
562 nm emission

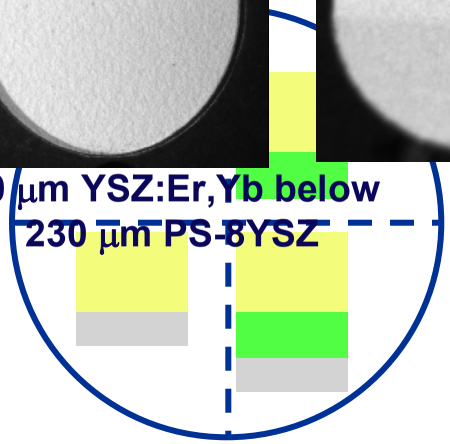
10 μm YSZ:Er,Yb below
145 μm PS-8YSZ

33 msec

4 min

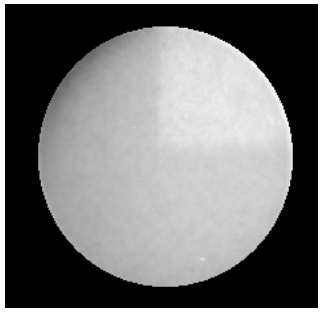
10 μm YSZ:Er,Yb below
230 μm PS-8YSZ



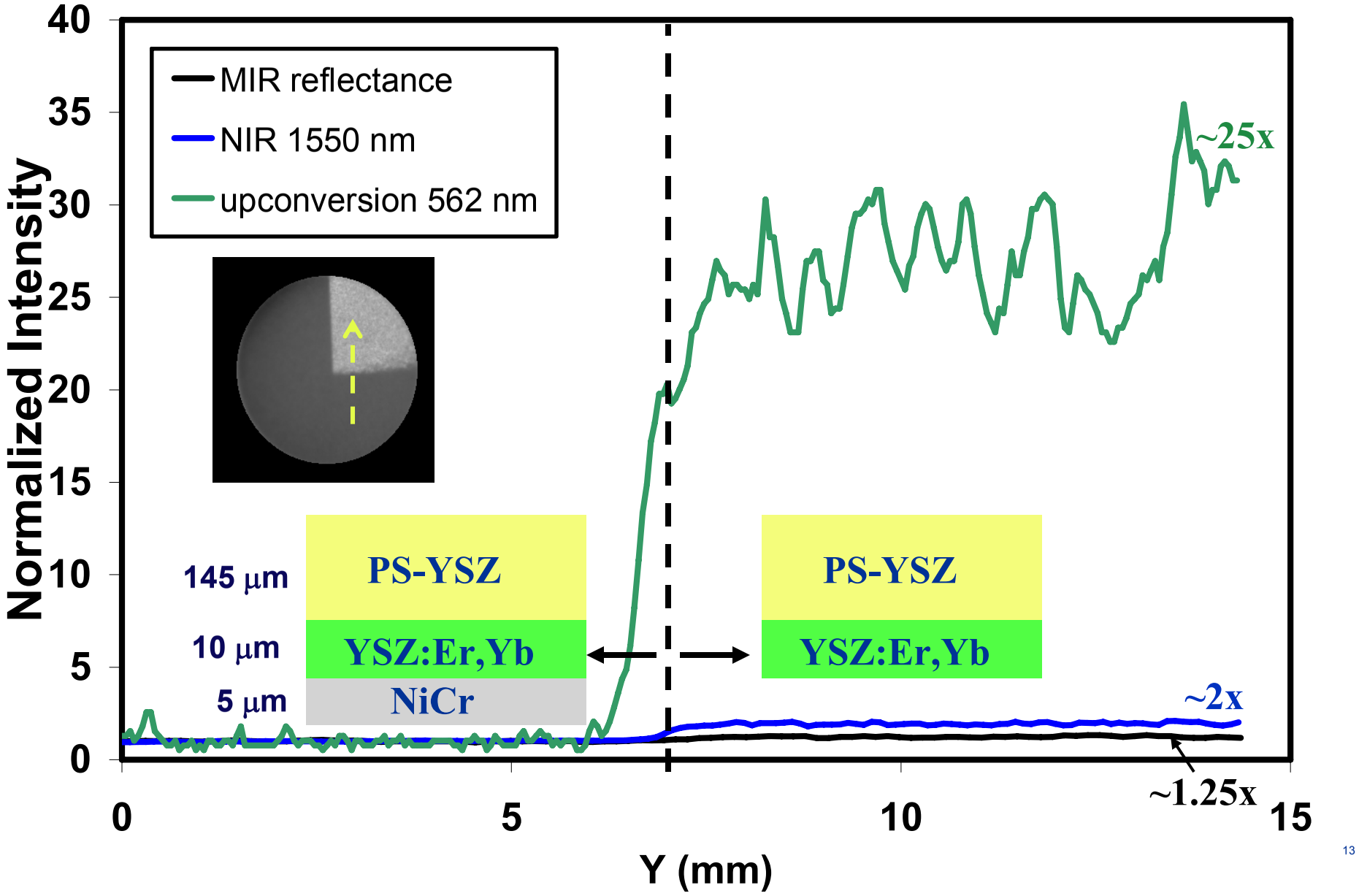
S-YSZ
co 204B-NS
236 μm

YSZ:Er,Yb
10 μm
6 μm YSZ:Er,Yb below
435 μm PS-8YSZ

NiCr
5 μm



Line Scans Traversing Border between "Attached" & "Delaminated" Sections of Plasma-Sprayed TBC

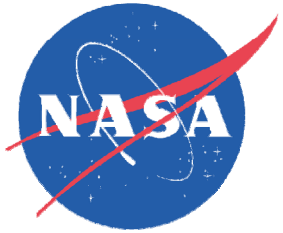


TBC Delamination Detection Score Card

Method	Modified TBC required	Delamination sensitivity		Fast	Thick PS-TBCs	Expensive camera needed
		EB-PVD	PS			
Visual inspection	No	✓	x	✓✓✓	x	x
MIR reflectance	No	--	✓	✓	x	✓
Luminescence						
Visible excitation & emission	✓	✓✓	✓	✓✓	x	x
NIR excitation & emission	✓	✓✓	✓✓	✓✓✓	✓✓✓✓	✓
Upconversion NIR excitation visible emission	✓	✓✓✓✓	✓✓✓✓	x	✓✓	x

Advantages of Er + Yb Co-Doping for TBC Delamination Detection

- Produces NIR and upconverision luminescence offering *exceptional* thickness probing and delamination contrast.
- Yb-assisted excitation “turns on” luminescence in co-doped sublayer *without* “turning on” interfering luminescence from Er impurities in undoped overlayer.



Acknowledgments

- Dennis Fox (plasma spraying)
- Jose Gonzalez (EB-PVD doped sublayers on plasma-sprayed coatings)
- Chuck Spuckler (modeling reflectance from delaminated TBCs)